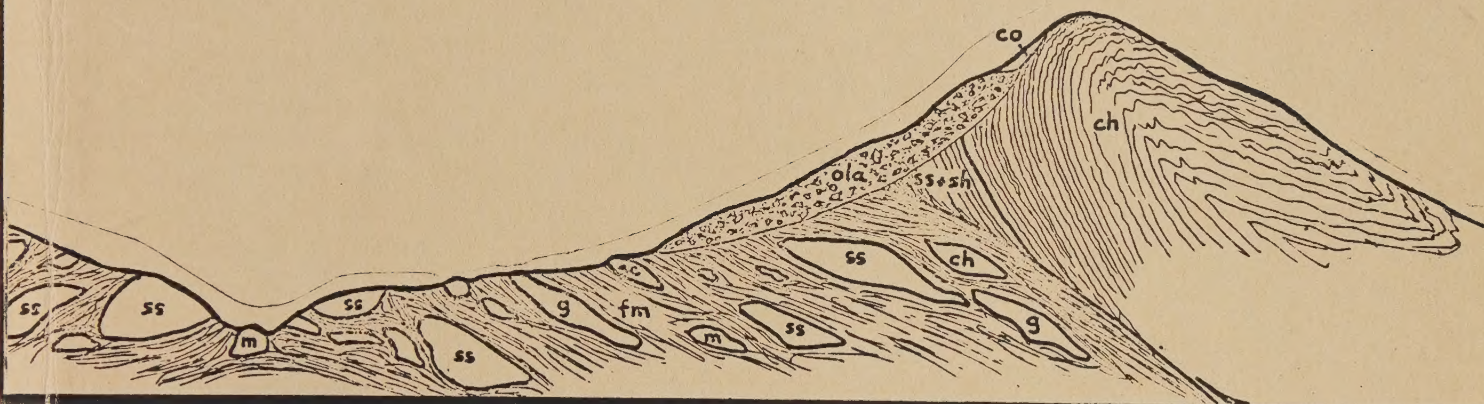

GEOLOGY AND SLOPE STABILITY IN MARIN COUNTY

A PILOT STUDY OF THREE AREAS

REPORT TO ACCOMPANY
GEOLOGIC AND SLOPE STABILITY MAPS
OF THE TENNESSEE VALLEY, LUCAS VALLEY,
AND NORTH COASTAL AREAS,
MARIN COUNTY, CALIFORNIA

by

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CONCLUSIONS

The three areas studied are widely separated and highly variable in geographic setting. However, all are characterized by sharp differences in the strength and stability of the rock formations and other geological materials underlying the surface soils--differences which commonly occur abruptly or within a few feet. Thus stability problems are not just soil deep, but involve the geological foundations of the ridges and slopes.

These areas are also characterized by very steep slopes, in many places exhibiting abundant evidence of being at or near the stability limits of the geological materials underlying them. Much of this land has a low capacity to absorb engineering changes without natural reactions that would be deleterious to the end products of the engineering.

RECOMMENDATIONS

1. Geologic reports based on detailed geologic mapping should be required for engineering development of slopes underlain by Franciscan melange (see page 4), and structures should be distributed on geologically stable sites thus indicated rather than by random or geometric distribution patterns. Such geologic studies should be in addition to the customary and necessary soil engineering studies required for site development.

2. On steep slopes, street widths and site excavations for structures should be kept to a minimum to limit the unstabilizing influences of substantial cut and fill in such settings. Modern street width standards appropriate to the flat lands cannot be applied to many of the slopes in the areas studied without resulting in costly landsliding.

3. The coast line is a special case where the surf is constantly at work undermining the bottoms of landslides or sea cliffs, which themselves are commonly derived from or composed of weak melange matrix. Although rates of sea cliff recession are not known in the two coastal areas mapped, average rates of 1 to 3 feet per year have been determined for parts of Pt. Reyes Peninsula. It is reasonable to assume that the minimum rate of retreat for these coasts would average at least a foot a year over the long range, and it is recommended that this amount of retreat be considered the absolute minimum in all long-range planning for these coastal areas.

4. The certainty of future great earthquakes occurring in this region should be kept firmly in mind in long range planning. Differential subsidence within areas of artificial fill on bay mud, as well as abundant landslides from weak or unconsolidated deposits on steep slopes, are results that can be broadly predicted from earthquakes approaching or exceeding 8 in magnitude originating anywhere in the central or north Bay Area.

INTRODUCTION

This report discusses some aspects of the geologic settings, particularly as they relate to "geologic hazards" and land-use planning, in the Tennessee Valley, Lucas Valley, and north coastal areas of Marin County, California. The geology of these areas was mapped in the winter and spring of 1971 by the California Division of Mines and Geology as part of a cooperative agreement with the County of Marin. The Marin County Planning Department selected the areas investigated. These were considered to be sufficiently representative of diverse settings to be suitable for a pilot study to determine applications of geologic information in land-use planning in the county.

Most of the results of these studies are presented in the form of geological and slope stability maps of each area and as tabulation of geological and engineering properties of mappable units. However, some aspects of the geologic settings that are particularly complex or likely to be poorly understood are briefly elaborated here to help explain interpretive criteria.

Perhaps it should be emphasized that a so-called geologic hazard arises only when man gets in the way of a perfectly normal geological event, or induces by his works an inevitable natural response in the geological environment that is not to his liking. Marin County occupies a geologic setting that is not static or stable, but is dynamic and has been so for at least the last 150 million years. It is changing constantly--incredibly slowly in most places but quite rapidly in some. The problem is to recognize settings where natural changes are taking place significantly fast in terms of man's use, where sudden changes might occur without help from man, and where man's works are likely to induce undesirable changes.

The following geological aspects are emphasized here because of their importance in evaluating potential geologic hazards in Marin County.

1. Nature of the Franciscan Formation, a complex assortment of geological materials that underlie the surface soils of much of Marin County east of the San Andreas Fault.

2. Slope, much of which is very steep and in many places shows evidence of being at or near the maximum angle permissible for stability of the underlying geological materials.

3. Wave erosion, the process that results in sea cliff retreat, which is important in two of the areas studies. The constant work of the surf at the base of sea cliffs is one of the most active and effective natural erosion processes known.

4. Seismicity, a necessary consideration because of the proximity of all of Marin County to the San Andreas and Hayward Faults, two major active faults that are both potential sources of great earthquakes.

SOME ASPECTS OF THE GEOLOGICAL MATERIALS

Brief descriptions of each of the rock formations and other mappable geological materials are given in the legends of the accompanying geologic maps and in tabulated form relating to some engineering properties. However, because of its broad importance in all respects, one geologic unit deserves expanded discussion. The "bedrock" underlying most of the three areas discussed herein is a complex, disrupted assemblage of different rock materials usually called the Franciscan Formation on published geologic maps. Although the Franciscan is widely distributed in the Coast Ranges and has been designated by that name on geologic maps since the early 1900's, we have only recently acquired something of a reasonable understanding of its make-up and origin.

The Franciscan rocks consist predominantly of sandstone and shale formed from sand and mud washed into the ocean during late Mesozoic time, roughly between 90 million and 150 million years ago. In places, particularly in Marin County, the formation also contains large amounts of greenstone (altered from lava erupted under the sea), of radiolarian chert (a hard sedimentary rock of deep sea origin), of serpentine (an altered igneous rock related in origin to the mantle of the earth, beneath the crust) and scattered small but resistant masses of some unusual types of metamorphic rocks, mostly bluish glaucophane schist. The appearances and other geologic characteristics of Franciscan rock types were admirably described by Bailey, Irwin, and Jones in 1964 (see references). Therefore, only one recently recognized aspect of the Franciscan, very important from the standpoint of slope stability, will be discussed here.

Some large areas are underlain by one or more of these rock types in such a way that bedding and other evidence of continuity can be traced for considerable distances. But in many places there is little or no continuity between outcrops of rock exposed in areas underlain by the Franciscan. A common sight in Marin County is an assortment of several different hard rock types exposed prominently within a few acres, usually as dark, picturesque masses protruding out of otherwise relatively smooth grassy slopes. Close inspection of excavations or gullies in such settings reveals that the grassy slopes between the rock outcrops are underlain by intensely sheared or pulverized rock material so incoherent and weak that it has been easily eroded, leaving exposed some of the hard masses of rock enclosed within it. Where steep these slopes commonly exhibit a "ravelled" appearance (usually most noticeable when the sun is low) that is characteristic of downslope creep of the soil or other near-surface materials. Such sheared and crushed rock material is normally found in great fault zones, and results from the grinding together of separate blocks of the earth's crust.

We now know that the disrupted, sheared, and crushed rock material in the Franciscan does indeed represent part of a great, ancient, now-inactive fault zone that resulted from the North American continental

mass mashing against and thrusting over that portion of the earth's crust that lay beneath the Pacific Ocean. This grinding action started some 150 million years ago and continued for many tens of millions of years. Masses of rocks of all sizes and available types that were strong enough to resist shearing were swept together in disoriented and unrelated assortments as the continent moved westward, the resistant blocks and slabs grinding up the weaker rock materials to yield the crushed matrix. The resulting assemblage of coherent masses of rock along with the weak, incoherent matrix in which they are embedded, is now referred to as melange, the name applied to it in 1968 by K. J. Hsu, who first described in print this aspect of the Franciscan.

Blocks and slabs of unsheared rock enclosed within the melange matrix range from a fraction of an inch to miles in dimensions. Many are composed essentially of a single rock type, such as the great mass of sandstone that makes up much of the upper slopes of Big Rock Ridge. Others are much more complex, such as the great contorted slab of greenstone, chert, sandstone, and shale that makes up the Marin Golden Gate Headlands (referred to in this report and on the geologic map of the Tennessee Valley area as the Marin Headlands Block). These coherent masses tend to have high strength characteristics and form steep, relatively stable slopes, although they commonly have landslides along their margins where the matrix of the underlying melange eroded away and undermined already steep slopes of the stronger rock above.

An understanding of the nature of the Franciscan melange is essential to recognition of its slope stability problems in Marin County. The variety of rock types and materials in it range widely in strength characteristics. More important, changes in strength from very strong to very weak commonly occur abruptly because the harder rock masses are likely to be enclosed in the most pulverized, weakest matrix.

In the past, the tendency in mapping the geology of such areas was to identify occasional outcropping rocks and assume continuity of rock beneath the vegetative cover between them. Such assumptions are likely to be invalid in melange terrain and lead to considerable misinterpretation regarding slope stability.

Clearly the melange matrix, being weakest, is the general controlling material in the stability of any slope it underlies. However, the masses of hard rock enclosed within it (sometimes called "knockers" by geologists) commonly act as buttresses when they are large enough, and many ridge spurs underlain by melange are supported at their toes by such natural retaining walls.

Another important aspect of the melange matrix is its tendency in many places to alter to swelling clays--that is, the matrix swells considerably when wet and shrinks when dry. This not only contributes to its tendency to "creep" downslope, but also subjects structures on it to great differential stresses at different seasons of the year. Special foundation designs are desirable in such environments to prevent structures from being disrupted.

The swelling clays, being relatively impermeable, also control ground water distribution and create an unusual-appearing distribution of springs. Many large "knockers", masses of hard rock in the melange matrix, contain abundant open fractures that can hold considerable amounts of water. When these are located near the crests of ridges, are accessible to rain water accumulation in winter, and are almost enclosed in impermeable membranes of melange matrix that has altered to swelling clays, they constitute natural water tanks and result in the many springs in Marin County located high on ridges.

SLOPE

The three areas studied have one topographic aspect in common--they are sharply dissected by steep-sided stream canyons with slopes commonly greater than 35 percent and in many places exceeding 60 percent. In addition, these slopes tend to be steepest just above the base. Above the canyon bases, the slopes tend to round off into broad summits on the ridges. The general pattern suggests geologically recent elevation of the land relative to sea level, causing increased gradient in the streams and enabling them to deepen their channels rapidly.

Land movements related to deformation of the earth's crust may account for some of this, for the California Coast Ranges are indeed an active region of the earth's crust. However, the principal cause of the gorge-like nature of these streams probably was the drop in sea level of some 300 feet during the last major glacial stage of the Pleistocene epoch, between about 25,000 and 10,000 years ago, when much of the water presently in the ocean was piled on the land in the form of ice. With this lowering of the base level for the trunk streams, these and most tributaries of Marin County's short, steep drainage system sharply incised gorges at the bottoms of their valleys. Subsequent melting of the ice caused sea level to rise to its present elevation. The bottoms of the gorges tributary to the ocean and the Bay were drowned and slowly filled with mud, silt, and sand to form the present flat-bottomed, steep-walled valleys.

The steep slopes created by this sharp dissection of the landscape represent a natural statement as to the stability limits of the geological materials underlying them. Where landslides and downslope creep of the surface zone are evident on natural slopes, the strength of underlying material has been exceeded by natural erosion. Undermining these by the usual deep cuts for streets and construction sites is likely to have costly results. The convex nature of the slopes also warns that undermining the steeper lower portions may result in landslides having a cumulative effect upslope (a threat that hangs over San Anselmo at Red Hill).

WAVE EROSION

The constant pounding of the ocean waves along the coast line is by far the most dynamic natural force working to change the face of Marin County. Where the coast is a cliff, waves use the explosive force of compressed air to fragment the rock at the base and undermine the face. Where the sea cliff is composed of strong, coherent rock, such as is the case in the vicinity of Tennessee Cove, the undermining usually results in periodic rock falls controlled by steep or vertical fractures, so that the entire face of the cliff remains very steep. But where the sea cliffs are made up of Franciscan melange, the relatively weak matrix reacts by landsliding--ordinarily by rotational landslides that leave vertical headwall scarps. The base of such a scarp remains supported for a time by the more gently-sloping body of the landslide.

Wave erosion is an effective and constant process, but its visible effects are sporadic. After mining down a section of sea cliff, the waves require a significant period of time, usually many years, to remove the debris and effect another undermine. Thus the sea cliff does not retreat at any constant rate, but by episodic increments. If a 40 foot section of a given portion of sea cliff collapses or slides down during a storm about every 40 years, the long-range average rate of retreat would be about a foot a year. Yet a person could live in the vicinity the better part of a lifetime without seeing such an event.

The long-range average rate of sea cliff retreat is not known for the areas studied. However, the north coastal area was examined in some detail to find evidence of currently active landsliding. As indicated on the geologic map of that area, the sea cliffs there are composed of Franciscan melange and are mantled by landslides, some 40% of which showed evidence of slide activity during the winter and spring of 1971. Six new scarplets were found representing incipient cliff retreat step backs of some 30 to 60 feet. That is, blocks 30 to 60 feet thick and 100 or more feet long are in the process of becoming unjoined along new slide planes. These are noted on the geologic map of the north coast area.

Recent study of the Pt. Reyes Peninsula has indicated that during the last 60 years or so, sea cliffs there have retreated at long-range average rates ranging from about a foot a year at Bolinas to about 3 feet a year for documented areas facing the open ocean (personal communication, Alan Galloway, California Academy of Sciences). The geological materials making up the sea cliffs of the Pt. Reyes Peninsula are entirely different from those studied here, but there is no reason to assume that these differences are significant in terms of the efficiency of wave erosion.

SEISMIC ASPECTS

No active faults, known to be potential sources of earthquakes, are known within the immediate confines of the areas mapped. However, all three areas studied (indeed, most of Marin County) are sandwiched between two major active fault zones, the San Andreas and the Hayward, both of which have generated great earthquakes during the 200 years of our recorded history of the area.

The northwest-trending San Andreas Fault Zone passes perhaps 3 miles offshore of Tennessee Cove and possibly within a quarter of a mile offshore of Dillon Beach. As shown on the accompanying geologic map of the north coastal area, projections from the Tomales Bay and Bodega areas indicate that the trace of surface rupture during the great 1906 earthquake passed some 3,000 feet offshore of Dillon Beach. The northwest-trending Hayward Fault Zone passes about 18 miles northeast of the San Andreas. Thus, one of the important potential causes of damaging seismic effects is well established for Marin County--potential proximity to the epicentral zones of strong earthquakes.

There are many factors that determine structural damage from earthquakes, some more important than proximity to the epicenter, and the total subject is quite complicated and in some aspects poorly understood. In general, different geological materials react differently to earthquakes, depending on such factors as density, cohesiveness, and water content. For example, massive well-cemented sandstone can respond only with relatively high frequency vibrations that tend to have relatively low amplitudes, whereas uncemented, water saturated valley alluvium can respond only with relatively low frequency, high amplitude vibrations. Thus in a strong earthquake, a structure with foundations in the sandstone might be subjected to "rippling"-like vibrations, while a nearby structure on alluvium is shaken violently by lurching-type vibrations. The current state of our knowledge of these and other damage-producing aspects of earthquakes is well summarized by P. J. Barosh in U. S. Geological Survey Bulletin 1279, published in 1969.

It can generally be stated that, with regard to the geological materials shown on our geologic maps, the greatest earthquake vibrations will occur within the superficial unconsolidated materials--bay mud, artificial fill, landslide deposits, alluvium, and colluvium. Deep unconsolidated deposits, especially bay mud covered with artificial fill, also can be expected to subside differentially because of ejection of water from between silt and clay particles at depth (a process that occurs slowly and locally within poorly consolidated, water saturated sediments without aid of known earthquake vibrations, which thus only accelerate a normal phenomenon). Of course, landslide deposits, and perhaps less obviously the deep colluvium deposits on steep slopes, are particularly vulnerable to downslope movement precipitated by earthquake vibrations. Such landsliding will be greatly multiplied if the great earthquake occurs during a period of saturation by rain as compared to an earthquake occurring at the end of the dry season when water loading and lubrication of such deposits would be at a minimum.

It was not possible to incorporate on our slope stability maps this great influence of seasonal variations of water saturation on the intensity of vibrations and of possible landsliding that might result from strong earthquakes. If one were to construct such maps for the special case of a great earthquake (greater than magnitude 8) occurring during a period of saturation immediately following a series of heavy rains, much of our zone 3, especially that underlain by colluvium on steep slopes, would have to be included in zone 4, our most unstable zone.

Figure 1 shows computed epicenters of all earthquakes recorded between 1934 and 1968 that originated in the Marin County area. These are reasonably well located for such data, but in many cases are probably only accurate to within a radius of about 3 miles. Many pre-1934 earthquake epicenters are also shown, but these are located with considerably less certainty because of low levels of seismograph refinements during the late 1800's and early 1900's (these may only be accurate to within a radius 6 miles or more). As a result of these location uncertainties, many of the epicenters are reported by gross latitude and longitude coordinates that tend to suggest north-south and east-west alignments of them when plotted on a map. Thus the distribution of epicenters on Figure 1 should not be used to infer locations or trends of earthquake-producing faults. The data used for compiling the map were obtained from the University of California Seismographic Laboratory and are the best available at present. A network of sensitive seismographs has recently been established in the north San Francisco Bay region, and this will yield accurate epicenter data for even very minor earthquakes in the future. Such accurate information might reveal active faults not presently recognized.

The "level" of seismicity that is indicated on Figure 1 is considered ominously low by many seismologists and geologists, particularly with regard to the paucity of epicenters along the San Andreas Fault Zone northwest of the Golden Gate. The only significant one there is the epicenter for the great "San Francisco" earthquake of 1906. It is known that the earth's crust to the west of the San Andreas is "drifting" northwest relative to that on the eastern side at some significant rate, perhaps 2 inches or more per year. Southeast of the Golden Gate there are hundreds of minor earthquakes each year centered along the fault zone, and along a segment near Hollister there is more or less constant displacement of the surface (called "creep") of about half an inch per year. Such activity is evidence of release of some of the constantly accumulating strain. However, northwest of the Golden Gate the San Andreas is considered to be "locked"; that is, it is a region where very little of the strain is relieved by frequent small or moderate-magnitude earthquakes. Instead, this region should be considered subject to infrequent major earthquakes generated by sudden large movements along the fault. The frequency of these major earthquakes cannot be reliably predicted at present, but known rates of strain accumulation suggest that at least one or two per hundred years should be anticipated.

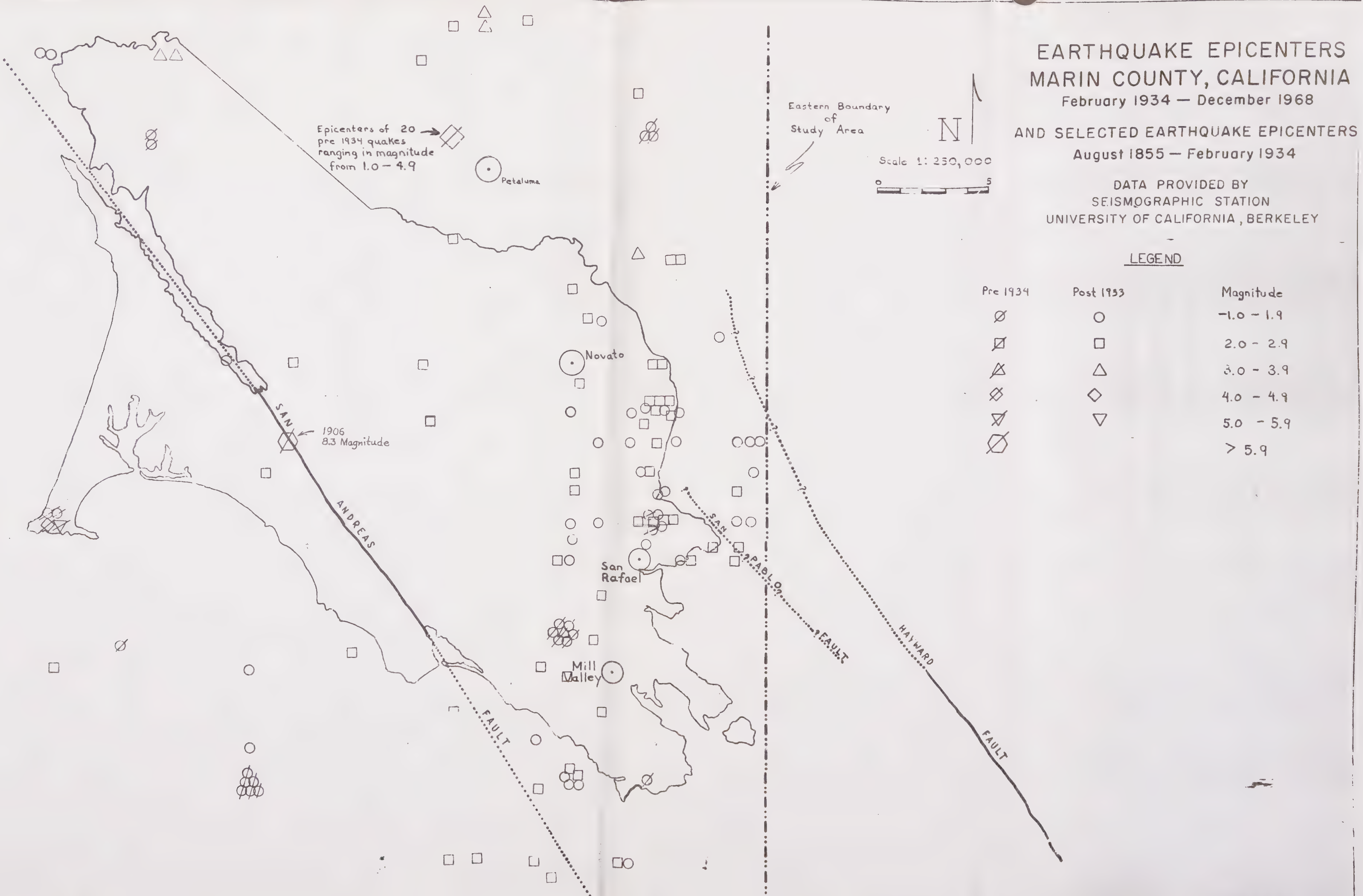

EARTHQUAKE EPICENTERS
MARIN COUNTY, CALIFORNIA
February 1934 — December 1968
AND SELECTED EARTHQUAKE EPICENTERS
August 1855 — February 1934
DATA PROVIDED BY
SEISMOGRAPHIC STATION
UNIVERSITY OF CALIFORNIA, BERKELEY
LEGEND
Pre 1934
Post 1933
Magnitude
-1.0 - 1.9
2.0 - 2.9
3.0 - 3.9
4.0 - 4.9
5.0 - 5.9
> 5.9
N
Scale 1: 250,000
0
5
Eastern Boundary of Study Area
Epicenters of 20 pre 1934 quakes ranging in magnitude from 1.0 - 4.9
Petaluma
Novato
1906
8.3 Magnitude
San Rafael
Mill Valley
SAN ANDREAS FAULT
SAN PABLO FAULT
HAYWARD FAULT

FIGURE 1

At the opposite extreme, the least stable category, zone 4, includes active or young landslides and slopes that show evidence of downslope creep of the surface, whether presently active or not. These should be considered naturally unstable slopes that can potentially fail without help from man. Since all sea cliffs are landslide scarps, and the surf is constantly working to undermine them, the boundary of zone 4 has been arbitrarily drawn at least 100 feet upslope from such scarps to take further expectable retreat into consideration.

Zones 2 and 3, between most and least stable, are broadly interpretative. Zone 3 (next to least stable) includes areas underlain by weak materials such as melange matrix, Merced Formation (in the north coastal area only), and colluvium where the slopes are so steep as to approach the stability limits of these materials. In melange terrain shown within zone 3, it is probable that more detailed geological mapping will indicate masses of resistant rock enclosed in the matrix, in which case such sites should be considered to be equivalent to zones 2 or 1 in relative stability.

These maps are broad evaluations of land stability patterns which have been prepared to aid in general land-use planning. They are not intended to be used for evaluation of individual sites in the place of engineering geologic studies necessary for proper planning of specific construction projects, nor are they suitable for this purpose.

Appendix A:

GEOLOGIC SETTING OF THE TENNESSEE VALLEY AREA

Tennessee Valley, called Elk Valley on old maps, is an unusual northeast-trending low gap through the Marin Peninsula less than 4 miles northwest of the Golden Gate. From the highest point on the valley floor, about midway along its length and 190 feet above sea level, it is drained by unnamed creeks to the northeast into Richardson Bay and to the southwest to Tennessee Cove on the Pacific Ocean. Total length of the valley is about 3 miles. It is bounded on the northwest by Coyote Ridge, which has a maximum elevation of 1,031 feet. On the southeast it is bounded principally by Elk Ridge, elevation 1,041 feet, and by Wolf Ridge, about 990 feet, which are en echelon and separated by a 600 foot saddle. The highest points on opposite flanking ridges are less than 2 miles apart. The gorge-like nature of Tennessee Valley, along with its low divide and other characteristics, led R. S. Holway to suggest in 1914 that it is probably the abandoned valley of an ancient westward-flowing river that was beheaded by the crustal deformation that led to the formation of San Francisco Bay and opening of the Golden Gate (Holway, 1914, pp. 86-90).

The geology of the Tennessee Valley area was mapped in the early 1900's by Andrew Lawson and his students at the University of California, and published in 1914 as part of the areal geology of the Tamalpais Quadrangle, contained in U. S. Geological Survey Geologic Atlas, San Francisco Folio (No. 193). This mapping was published at a scale 1:62,500 and is too generalized for use in determining broad slope stability characteristics for planning purposes.

Approximately the northern two-thirds of the area mapped around Tennessee Valley is underlain by Franciscan melange. This is in fault contact with a very large mass of unsheared rock referred to herein as the Marin Headland Block. Composed of greenstone, chert, sandstone, and shale that are all tightly folded but not sheared, the Marin Headland Block is presumably a great slice of ancient sea floor that resisted dismemberment in the melange-making process. It underlies all of the Marin Peninsula south of its boundary fault contact that diagonally crosses Tennessee Valley in an east-west trend. This boundary fault is nearly vertical in the western half of its trace, but in the eastern half it dips gently to the south. Where it is crossed by the Marincello access road, it is nearly horizontal and marked by landslides in weak, highly altered sandstone and chert exposed in the roadcuts.

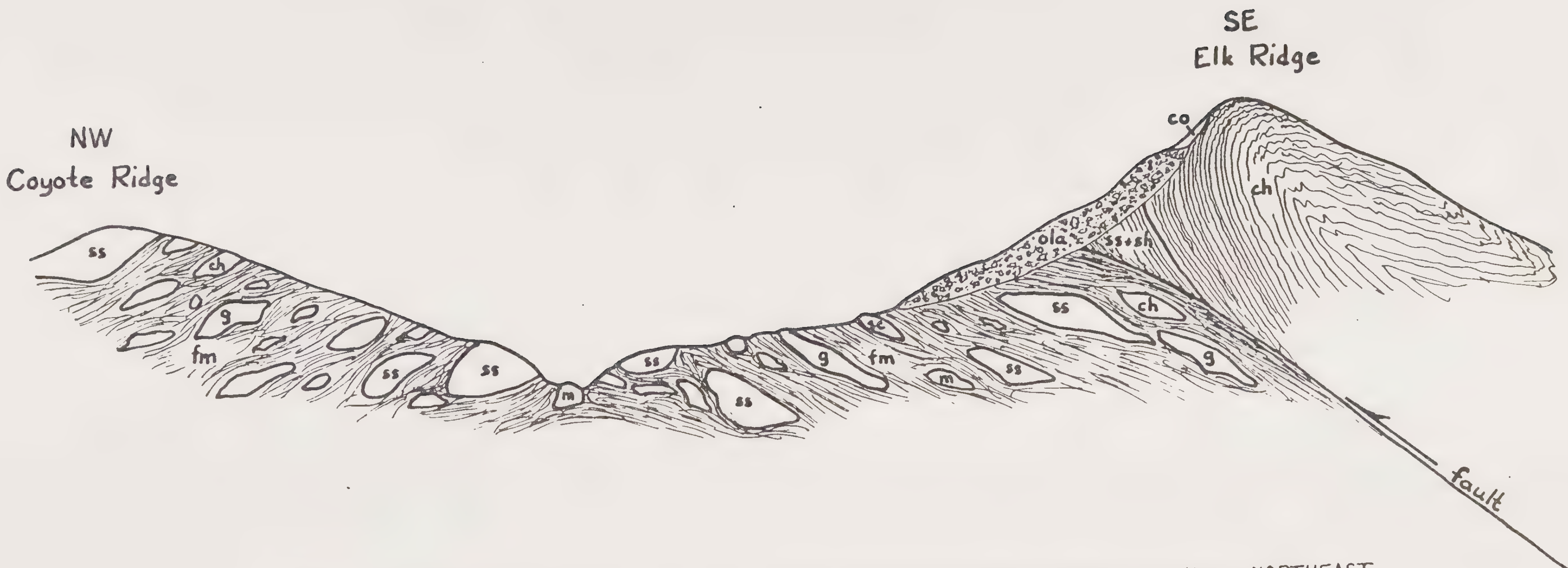
The Marin Headland Block is characterized by long, broad or sharp ridges and spurs held up by more or less continuously outcropping colorful, thin-bedded chert. The beds mostly dip to the south but are actually tightly folded and overturned as indicated to some extent in the accompanying diagrammatic cross section. Chert is a very stable rock chemically, so is not attacked and altered to clay by weathering processes as are sandstone, shale, and greenstone with which it is interbedded. This is the reason that erosion has left the chert to

INDEX MAP TO THE TENNESSEE VALLEY AREA

Area investigated for this report is outlined in heavy dashed lines. It is subdivided into two geological "provinces" that have different gross geological and slope stability characteristics. These are the Marin Headland Block and the Franciscan Melange, separated from each other by an east-west trending fault.

Boundary fault between the Marin Headland Block, to the south, and the Franciscan melange, to the north.

FIGURE 2



DIAGRAMMATIC CROSS SECTION ACROSS TENNESSEE VALLEY NEAR ITS CENTRAL DIVIDE, LOOKING NORTHEAST

To the southeast, Elk Ridge is made up of a tightly folded sequence of thin-bedded chert along with some sandstone and shale--all part of the Marin Headland Block. These are in contact with Franciscan Melange along a fault that dips gently to the south here (but is almost vertical to the west, near the ocean).

Franciscan Melange, which underlies most of this area, is largely intensely sheared rock material that encloses small to large blocks and lenses of various rock types that were strong enough to resist the shearing and crushing action of the melange-forming process. Melange matrix is easily eroded, a process that probably undermined the more resistant chert of Elk Ridge long ago to yield the old landslide deposits on its flanks. Resistant masses of rock within the melange commonly support ridges and act as buttresses for the weak matrix on steep slopes.

Symbols and colors on this diagram are similar to those used on the geologic map.

co – colluvium.
ola – ancient landslide deposit.

fm – undifferentiated Franciscan Melange.
ss – sandstone.
ss+sh – thinly bedded sandstone and shale.

ch – chert.
g – greenstone.
m – metamorphic rocks.
sc – silica-carbonate rock.

FIGURE 3

GENERALIZED DESCRIPTION AND SOME ENGINEERING PROPERTIES
OF SOME GEOLOGIC MAP UNITS IN THE TENNESSEE VALLEY AREA

NAME AND MAP SYMBOL	LITHOLOGY	SOIL DEVELOPMENT	PERMEABILITY	SLOPE STABILITY	EARTHQUAKE STABILITY
Landslide deposits (la, ola)	Highly variable. Rock fragments of all sizes in a clay matrix. Old landslide deposits (ola) in or from the Marin Headland Block contain chert as the predominant rock fragments.	None or very little on younger slides, moderate on older slides.	Variable. Generally low in younger deposits (la), but moderate in some old deposits (ola).	Cut slopes in landslide deposits are generally unstable. Old deposits (ola) are presently stable, but must be considered sensitive to undercutting or changes in naturally developed drainage efficiency.	Very low for young deposits along the coast to moderate for some old stabilized deposits flanking Elk Ridge.
Bay Mud (mu)	Mainly silty, carbonaceous clay with very minor amounts of sand. Probably contains shell fragments and some lenses of peat and sand. Soft near top, moderately stiff at depth. Plastic and swelling when wetted, shrinks and becomes hard when dry.	None. Generally below water table.	Impervious, except sand lenses.	Unstable	Low. Subject to lurching and differential compaction.
Artificial fill on bay mud (af/mu)	Rock waste, soil, silt, clay, some dredged bay mud.	None	Mostly low because of a abundant clay materials.	Low because of unconsolidated nature and proximity to the water table.	Generally very low to low. Lurching movement and differential subsidence likely because of underlying soft mud.
Alluvium (al)	Primarily clayey silt with small percentage of pebbles. Essentially without bedding.	Dark organic soils.	Low	Low	Low
Colluvium (co)	Unsorted rock fragments, sand, silt, clay. On Franciscan Melange high in sand, silt, and clay fractions, largely derived from sandstone and shale. On Marin Headland Block largely chert fragments.	Deposits on Franciscan Melange high in fragments that alter to clay by weathering, yielding deep soil. Chert-rich deposits little affected by weathering.	High	Low	Low to very low when on steep slopes or when saturated. Moderate where on gentle slopes and dry.
Franciscan Melange (fm)	Matrix of sheared to intensely pulverized rock material containing scattered small to large shear-resistant blocks (knockers) of various rock types, especially sandstone, greenstone, chert, serpentine, and metamorphic rocks. Melange matrix is largely ground-up sandstone and shale, but crushed debris derived from other rocks, especially greenstone, give it different properties when present. Properties given are for Melange matrix. Important "knocker" rock types described separately.	Moderate to well-developed soils form on Melange matrix derived entirely from sandstone and shale. Abundant greenstone debris yields soils rich in swelling clays that tend to have a bluish-green subsoil. Alters and erodes so easily that exposures of Melange matrix are rare on natural slopes.	Low to very low. Commonly forms impermeable membrane or envelope around unsheared masses of rock enclosed in it. These in turn, if sufficiently large and fractured, constitute local ground water reservoirs that are the sources of springs and seeps upslope and near the crests of ridges in Melange terrain.	Low. In many places subject to down slope creep of material at and near the surface, especially where rich in swelling clays.	Moderate to high on flat or low-angle slopes. Moderate to low on steep slopes because of tendency to slope failure.
Sandstone (ss)	Tough, fine- to coarse-grained, thick bedded graywacke. Gray to dark gray at depth, but normally weathered near the surface to brown or pale buff color.	Weathers easily to soil.	Has no intergranular permeability; thus permeability determined by joint or fracture density and spacing. Generally low because of clay fill in joints.	High in unsheared sandstone, ranging through moderate to low for sheared sandstone.	High
Chert (ch)	Thin beds of hard brittle, radiolarian chert, one or a few inches thick, alternating with thin films or layers of shale. Locally thick beds or lenses of chert or jasper. Thin-bedded chert mostly tightly folded and closely jointed at right angles to the bedding.	Very stable, not altered by weathering processes. Yields only thin, rocky soils. Crops out prominently.	High because of abundant, closely spaced fractures. As with the sandstone, chert lacks permeability except for joints or other fractures.	High	High
Greenstone (g)	Medium to fine grained volcanic rocks, mostly originally basalt, that exhibit pillow structure where well exposed and are slightly recrystallized to yield a dull green color.	Weathers easily to yield a dark, reddish brown soil that is likely to be deep on gentle slopes or even moderately deep on steep slopes.	Low except where fractured.	High	High

occupy the high ground while wearing the other rocks down. It is also one of the principal reasons for the general high stability of many very steep slopes in the Marin Headland Block.

In sharp contrast, the area of Franciscan melange is marked by sparse and sporadic outcrops of many different rock types, but principally varieties of sandstone. The bulk of this area is underlain by sheared material of the melange matrix that erodes most easily of the Franciscan bedrock materials. The matrix is not exposed, forming grassy slopes often marked by a somewhat bumpy or ravelled appearance. All of the aspects of the Franciscan melange discussed earlier are evident in this area.

Valley heads and ravines in the Tennessee Valley area are commonly deeply mantled with colluvium, rock fragment debris and soil material that normally accumulates on slopes. As noted on the legend of the geologic map of this area, general characteristics of the colluvium on Franciscan melange are different from those on the Marin Headland Block. Both tend to be porous, but the melange debris is largely fragments of sandstone and shale, both of which are attacked by weathering processes, while the Headland colluvium is mostly stable chert fragments. These differences lead to different characteristics of slope stability, for the colluvium on the melange is rather densely pockmarked with mudflow scars which are lacking on the Headland Block. These scars are evidence of one of the principal erosion processes in this area.

Mudflow scars are cup- or scoop-shape depressions that are the spaces evacuated suddenly by masses of instantly-liquified colluvium or soil that flowed rapidly down slope to some relatively flat level. These flows are caused by total saturation during rare intense rain storms and only involve superficial material, not bedrock. The scars have characteristic dimensions of about 50 feet long, 25 feet wide, and 6 feet deep, and represent significant evidence of little understood but potentially hazardous geological conditions. They certainly indicate the potential of the given soil and colluvium to liquify instantly. In recent years, many houses in Marin County located in the paths of such mudflows have been damaged or destroyed. Some of these flows have been entirely the result of natural causes, but others have been the result of poorly-constructed or disrupted drainages along roads and streets diverting too much water into areas of colluvium below.

The only indications of mineral deposits of potential commercial interest found in the Tennessee Valley area were small outcrops and scattered loose pieces of manganese oxide observed in two localities. One of these is in the vicinity of the Marincello access road just upslope from the fault contact between the Marin Headland Block and Franciscan melange. The other locality is about 4,000 feet northeast of Tennessee Cove. Both localities are indicated by symbols on the geologic map and are characterized by masses of black manganese oxides of probable manganese ore grade. Such material is associated with chert in many places in the California Coast Ranges, but only very rarely have such occurrences been found to represent commercially-interesting quantities or ore.

Appendix B:

SOME GEOLOGIC ASPECTS OF THE COASTAL AREA OF MARIN COUNTY NORTH OF DILLON BEACH

The oldest geological materials underlying the Marin County coastal area north of Dillon Beach are those of the Franciscan melange. These are well exposed in the bodies and headwalls of the landslides that mantle the coast line, where they exhibit all of the melange characteristics mentioned earlier in this report.

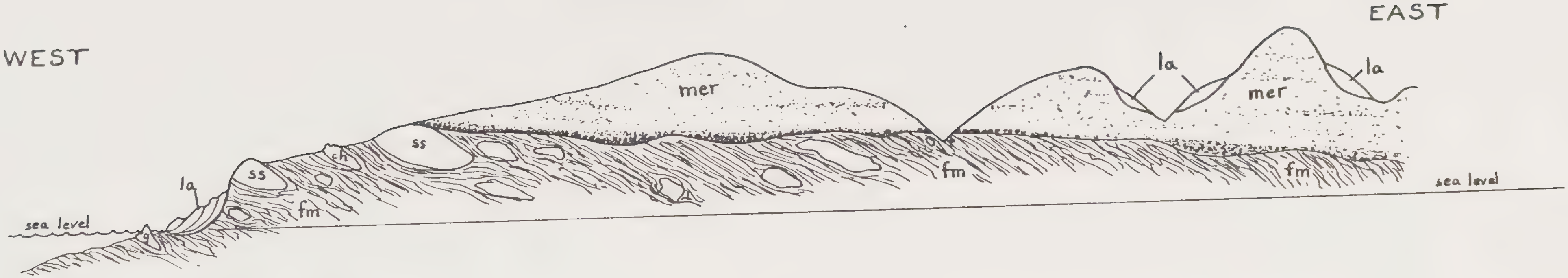
Most of the hills and ridge crests inland from the sea cliffs in this area are made up largely of poorly-cemented clayey sandstone and sandy mudstone called Merced Formation on geologic maps. These sedimentary materials are geologically quite young--many tens of millions of years younger than the Franciscan melange. They were deposited in a broad embayment that resulted from local subsidence below sea level of the old, deeply eroded, uneven melange surface during late Pliocene time, perhaps 4 million years ago.

Following deposition of as much as 500 feet of Merced sediments the subsidence process reversed, elevating these sediments and their melange base above sea level. The meandering channels of Stemple and Americano Creeks were initiated on the "mudflats" of the Merced bay bottom as it emerged slowly above the sea; and as uplift slowly continued these channels were incised through the entire thickness of Merced sediments and into the underlying melange. The last great stimulus to deepening of these channels was the lowering of sea level by about 300 feet during the last Ice Age, between about 25,000 to 10,000 years ago. Since the latter date, rise in sea level to its present status flooded these deepened channels to yield the fjord-like lagoons of Estero de San Antonio (the drowned Stemple Creek valley) and Estero Americano. Patches and narrow remnants of marine terrace deposits along the coast as much as 100 feet above sea level probably represent a high stand of the sea prior to the last Ice Age.

The sandstone and mudstone of the Merced Formation are "cemented" only by compaction except for a few isolated local zones (such as at Elephant Rocks, near Dillon Beach, where in coarse sandstone the sand grains are reasonably well cemented by calcite). As a result, most of these Merced materials are weak and susceptible to landsliding on moderate to steep slopes and in road cuts more than a few feet high. They are also highly susceptible to erosion when stripped of vegetative cover. Many of the old fence lines located on Merced Formation are now on mounds six inches to a foot high with regard to adjacent ground, indicating a remarkable amount of erosion that likely resulted from overgrazing and cultivation during the last century.

GENERALIZED DESCRIPTIONS AND SOME ENGINEERING PROPERTIES
OF IMPORTANT GEOLOGIC MAP UNITS IN THE COASTAL AREA NORTH OF DILLON BEACH

NAME AND MAP SYMBOL	LITHOLOGY	SOIL DEVELOPMENT	PERMEABILITY	SLOPE STABILITY	EARTHQUAKE STABILITY
Landslide deposits (la)	Highly variable. Those along the coast and others in Franciscan Melange contain rock fragments of all sizes in a clay-rich matrix. Those derived from Merced Formation are all fine-grained sand-clay mixtures similar in texture to the source material.	None or very little.	Generally low.	Unstable along the coast, where downward movement can be expected constantly or intermittently because of undercutting. Stability generally low in other areas.	Very low.
Alluvium (al)	Mainly fine-grained silt rich in clay, sand, and organic debris. Similar in many respects to San Francisco Bay mud.	None	Low	Unstable. Characteristics likely to be similar to younger San Francisco Bay mud.	Low. Subject to lurching and differential compaction.
Terrace deposits (ter)	Gravel and gravelly sand on ancient wave-cut terraces along the coast. Slightly to moderately cemented in places by brown iron oxides.	Moderately deep sandy organic soils.	Moderate to high.	Moderate to low, depending on presence or lack of cementation.	Moderate
Merced Formation (mer) (mercs)	Largely sandy or silty mudstone that is "cemented" only by compaction. Locally, particularly at and near its base, has beds of coarse-grained pebbly sand that is well cemented by calcite in places (mercs). Generally massive or poorly bedded.	Poor thin soils on exposed slopes because overgrazing and resulting erosion in the past. Thick black organic soils in swales and closed depressions that tend to be boggy.	Low to very low because of fine-grained nature and abundant clay. Tends to be boggy in swales.	Low, except for locally cemented sandstone (mercs). Most Merced mudstone in this area will fail even in shallow vertical cuts when saturated. Abundant natural landslides on steep to moderate slopes. Gullies readily when stripped of grass cover.	Low. Should be expected to respond [illegible] earthquakes with high amplitude vibrations. These would precipitate [illegible] slides in steep to moderate [illegible].
Franciscan Melange (fm)	Matrix of sheared to intensely pulverized rock material containing scattered small to large shear-resistant blocks (knockers) of various rock types, especially sandstone, greenstone, chert, and metamorphic rocks. Melange matrix is largely ground-up sandstone and shale, but crushed debris derived from other rocks, especially greenstone, give it different properties when present. Properties given are for Melange matrix. Important "knocker" rock types are described below separately.	Moderate to well-developed soils form on Melange matrix derived entirely from sandstone and shale. Abundant greenstone debris yields soils rich in swelling clays that tend to have a bluish-green subsoil. Alters and erodes so easily that exposures of Melange matrix are rare on natural slopes except in landslide scarps along sea cliffs.	Low to very low.	Low. In many places subject to down slope creep of material at and near the surface, especially where rich in swelling clays.	Moderate to hi on flat or low angle slopes. Moderate to lo on steep slope because of tendency to slope failure.
Sandstone (ss)	Tough, fine- to coarse-grained, thick bedded graywacke. Gray to dark gray at depth, but normally weathered near the surface to brown or pale buff color.	Weathers easily to soil.	Has no intergranular permeability; thus permeability determined by joint or fracture density and spacing. Generally low because of clay fill in joints.	High in unsheared sandstone, ranging through moderate to low for sheared sandstone.	High
Shale and thin-bedded sandstone (ssh)	Mainly shale with some interbedded sandstone layers that are less than an inch to several inches thick.	Only covered with thin clayey soils in this area.	Low	Moderate. Landslides in this unit are on very steep natural slopes.	Generally high



DIAGRAMMATIC GEOLOGIC CROSS SECTION EAST-WEST ACROSS THE COAST NORTH OF ESTERO SAN ANTONIO

Franciscan Melange comprises the bedrock making up the sea cliff and forming a broad platform beneath the Merced Formation. Melange is mostly intensely sheared rock material that contains large and small lenses and blocks of hard rock that are not sheared. The melange is geologically old, having been formed in late Jurassic and Cretaceous time, between about 90 million and 150 million years ago.

After it was formed, the melange was elevated to make up part of the early Coast Ranges. By late Pliocene time, about 4 million years ago, the earlier ridges of this area had been planed off by erosion and the coastal region of northern Marin County and southern Sonoma County was depressed below sea level. In the large embayment thus formed, sediments we call the Merced Formation were deposited on the old irregular surface.

The Merced Formation is largely made up of massive clayey sandstone and sandy mudstone that shows little evidence of bedding and is generally poorly cemented. In places, particularly at its base, it is rich in pebbles and coarse sand. Relatively recent uplift has left the Merced sediments exposed to erosion and its bedding tilted gently to the east.

Symbols on this cross section are the same as those on the geologic map:

la — landslide deposit
mer — Merced Formation
ss — sandstone
ch — chert
g — greenstone
fm — undifferentiated Franciscan Melange

FIGURE 4

The Merced sediments generally have low to very low permeabilities because of their high content of clay and other fine-grained minerals. This results in many upland swampy areas during the winter where slopes are low, and these tend to remain soggy late in the spring.

Estero de San Antonio and Estero Americano are both long, sinous, brackish-water lagoons that are only slightly flushed by natural water circulation. Both are fed only by minor tributary streams and are isolated from tidal flushing durng much of the year by sand bars across their entrances. Thus both are highly susceptible to man-made pollution.

There are no known mineral deposits of potential commercial interest in the north Marin coastal area studied for this report.

Appendix C:

LUCAS VALLEY AREA--GENERAL GEOLOGIC CHARACTERISTICS

This irregularly shaped project area contains parts of three distinctive physiographic and geologic features that include one lowland and two upland areas.

The lowland block is nearly rectangular (see accompanying index map), and is comprised of valley bottom land dotted with low, gently eroded hills. A contact between typical melange material and a large mass of sandstone and shale traverses the lowland block. Here, as elsewhere in the Lucas Valley area, the nature of bedrock material is a very significant factor controlling slope stability. The undifferentiated melange bedrock material of this block contains extensive areas subject to downslope creep. These are marked by numerous small slides in the surficial parts of the creep zones. The sandstone and shale mass is generally stable but is marked by smooth "U"-shaped (in cross-section profile) colluvial filled tributary drainages. These U-shaped valleys are believed to be the sites of flow slides of colluvial material. That is, material similar to that which now occupies the upslope drainages has in the past liquefied and thus been transported as flow slides to the main valley floor below. Detailed studies of these colluvial filled tributaries are recommended to determine their stability before permitting the emplacement of fill upon them or before allowing the "toes" of them to be removed. Such colluvial fill is relatively stable under most conditions; problems probably can be expected only after intense rainfall, and then perhaps only after being undercut or subjected to strong earthquake vibrations when saturated. Alluvial material is generally stable except along the deeply incised creeks, such as Miller Creek, where failure of steeply cut banks has occurred.

The two upland areas, separated from one another by Lucas Valley, include the foothills of Loma Alta, to the south, and part of Big Rock Ridge, to the north. The lower flanks and spur ridges of Loma Alta are underlain by the relatively weak Franciscan melange, which for the most part contains relatively small, resistant masses of rock (knockers) enclosed in sheared melange matrix material. The matrix is unstable and shows evidence of slow but persistant failure on most slopes. Where apparently stable on slopes, the matrix appears to be supported or protected by the individual knockers, which are often observed to be the local bedrock on ridgecrests or to be at the foot of ridge spurs. Some knockers are quite large (see large blue area, representing a 7/10-mile long sandstone knocker, on west central part of geologic map). These masses are quite stable, but colluvial cover (weathered rock debris and soil) on their flanks may be thick and relatively unstable. It is difficult to recognize all of the sandstone knockers in the field, for many of them are poorly exposed; thus additional stable sandstone masses will undoubtedly be found in this block by more detailed mapping.

The Big Rock Ridge block is relatively stable. A large sandstone mass forms the eastern part adjacent to Miller Creek Road. Small sites of flow slides are present in tributaries near the crest of this part of the block, but in general slopes here are quite stable. Heavy forests

GENERALIZED DESCRIPTION AND SOME ENGINEERING PROPERTIES
OF SOME GEOLOGIC MAP UNITS IN THE LUCAS VALLEY AREA

NAME AND AP SYMBOL	LITHOLOGY	SOIL DEVELOPMENT	PERMEABILITY	SLOPE STABILITY	EARTHQUAKE STABILITY
rtificial Fill (af)	Waste rock of sandstone, shale and serpentine, soil silt and clay. (description refers only to fill not to cut areas of cut and fill locations.)	none	Moderate		
rtificial ill on ay mud af/mu)	Rock waste, soil, silt, clay, some dredged bay mud.	none	Mostly low because of a abundant clay materials.	Low because of unconsolidated nature and proximity to the water table.	Generally very low to low. Lurching movement and differential subsidence likely because of underlying soft mud.
ay Mud (mu)	Mainly silty, carbonaceous clay with very minor amounts of sand. Probably contains shell fragments and some lenses of peat and sand. Soft near top, moderately stiff at depth. Plastic and swelling when wetted, shrinks and becomes hard when dry.	None or very little below water table.	Impervious, except sand lenses.	Unstable	Low, subject to lurching and differential compaction.
lluvium (al)	Sand, gravel, and silt. In intertonguing lenses.	Sandy soils	High	Low	Moderate
andslide eposits (la, ola)	Highly variable. Rock fragments of all sizes in a clay matrix.	None or very little on younger slides, moderate on older slides.	Variable. Generally low in younger deposits (la), but moderate in some old deposits (ola).	Cut slopes in landslide deposits are generally unstable. Old deposits (ola) are presently stable, but must be considered sensitive to undercutting or changes in naturally developed drainage efficiency.	Very low for young deposits along the coast to moderate for some old stabilized deposits.
olluvium (co)	Colluvial aprons at base of Franciscan Melange outcrops is high in silt and clay fractions, largely derived from sandstone, shale and greenstone. Colluvium on sandstone and shale slabs is primarily sand sized grains with clay coatings and shale fragments.	Deposits on Franciscan Melange high in fragments that alter to clay by weathering, yielding deep soil. Very little on stream colluvial deposits on the sandstone and shale slabs.	High, except low in colluvial aprons.	Low	Low to very low when on steep slopes or when saturated. Moderate where on gentle slopes and dry.
andstone (ss)	Tough, fine- to coarse-grained, thick-bedded graywacke. Gray to dark gray at depth, but normally weathered near the surface to brown or pale buff color.	Weathers easily to soil	Has no intergranular permeability; thus permeability determined by joint or fracture density and spacing. Generally low because of clay fill in joints.	High in unsheared sandstone, ranging through moderate to low for sheared sandstone.	High
hale and fine-rained sandstone nd shale (sh & ss)	Siltstone, shale, to slatey shale, and various proportions of fine-grained sandstone interbeds.	Weathers easily to soil	Moderate to low, rock contains abundant closely spaced fractures and bedding planes which permits passage of ground water. Fine grained dense rock otherwise has low permeability.	Moderate. This unit occurs in large relatively stable s slabs; unlike other parts of Franciscan.	Moderate on weathered slopes to high on cut benches of beds having favorable attitudes (vertical beds or without dip-slope orientations)
hert (ch)	Thin beds of hard brittle, radiolarian chert, one or a few inches thick, alternating with thin films or layers of shale.	Very stable, not altered by weathering processes. Yields only thin, rocky soils. Crops out prominently.	High because of abundant, closely spaced fractures As with the sandstone, chert lacks permeability except for joints or other fractures.	High	High
reenstone (g)	Medium to fine grained volcanic rocks, mostly originally basalt, are slightly recrystallized to yield a dull green color.	Weathers easily to yield a dark, reddish brown soil that is likely to be deep on gentle slopes or even moderately deep on steep slopes.	Low except where fractured.	High	High
erpentine (sp)	Sheared serpentine, minor silican-carbonate rock.	None to very little at extreme west end of map area.	Very low	High	High, except at extreme west end of map area where moderate
etamorphic ocks (m)	Mica schist, glaucophane schists.	None, to thin on glaucophane schist areas which may be somewhat exaggerated on geologic map.	Low, occurring mainly along foliation fracture planes of near surface rocks.	Weathered vertical on flanks of ridge has low stability whereas flat ridge crests are relatively stable.	Moderate to high on flat areas, Moderate to low on steep slopes
anciscan lange differentiated (fm)	Matrix of sheared to intensely pulverized rock material containing scattered small to large shear-resistant blocks (knockers) of various rock types, especically sandstone, greenstone, chert, serpentine and metamorphic rocks. Melange matrix is largely ground-up sandstone and shale but crushed debris derived from other rocks, especially greenstone which give it different properties when present. Properties given are for Melange matrix. Important "knocker" rock types described separately.	Moderate to well-developed soils form on Melange matrix derived entirely from sandstone and shale. Abundant greenstone debris yields soils rich in swelling clays that tend to have a bluish-green subsoil. Alters and erodes so easily that exposures of Melange matrix are rare on natural slopes.	Low to very low. Commonly forms impermeable membrane or envelope around unsheared masses of rock enclosed in it. These in turn, if sufficiently large and fractured, constitute local ground water reservoirs that are sources of springs and seeps upslope and near the crests of ridges in Melange terrain.	Low. In many places subject to down slope creep of material at and near the surface, especially where rich in swelling clays.	Moderate on flat or low-angle slopes. Moderate to low on steep slopes because of tendency to slope failure.

cover a large area northwest of northern Las Gallinas Road, and geologic mapping of bedrock materials there is difficult because of the thick duff and colluvial cover. Although topographic evidence is suggestive of old slides in parts of the forest, strong field evidence of them was not found. Development of such dense forest land should only be done with great caution inasmuch as the slopes are presently covered with colluvium that would be prone to sliding or rapid erosion in the absence of the forest cover.

The mapped western part of the Big Rock Ridge block, being the southwest facing slope along Lucas Valley, is underlain by alternate bands of Franciscan melange and large masses of sandstone and shale. The parts of the slope underlain by melange are characterized by hummocky slopes and the small rocky outcrops of chert knockers. On slopes underlain by sandstone and shale, the characteristic colluvial-filled sites of flow slides are prominent. Apart from two large bedrock failures in the western part of the map area, Big Rock Ridge seems fairly stable, with the bands of sandstone and shale providing support to the bands of weaker melange.

Steep slopes underlain by sandstone near the top of Big Rock Ridge are relatively stable, whereas gentler slopes underlain by melange on the Loma Alta block, across Lucas Valley, are relatively unstable. Clearly the nature of the bedrock is more critical to slope stability than the steepness of slope in the Lucas Valley area.

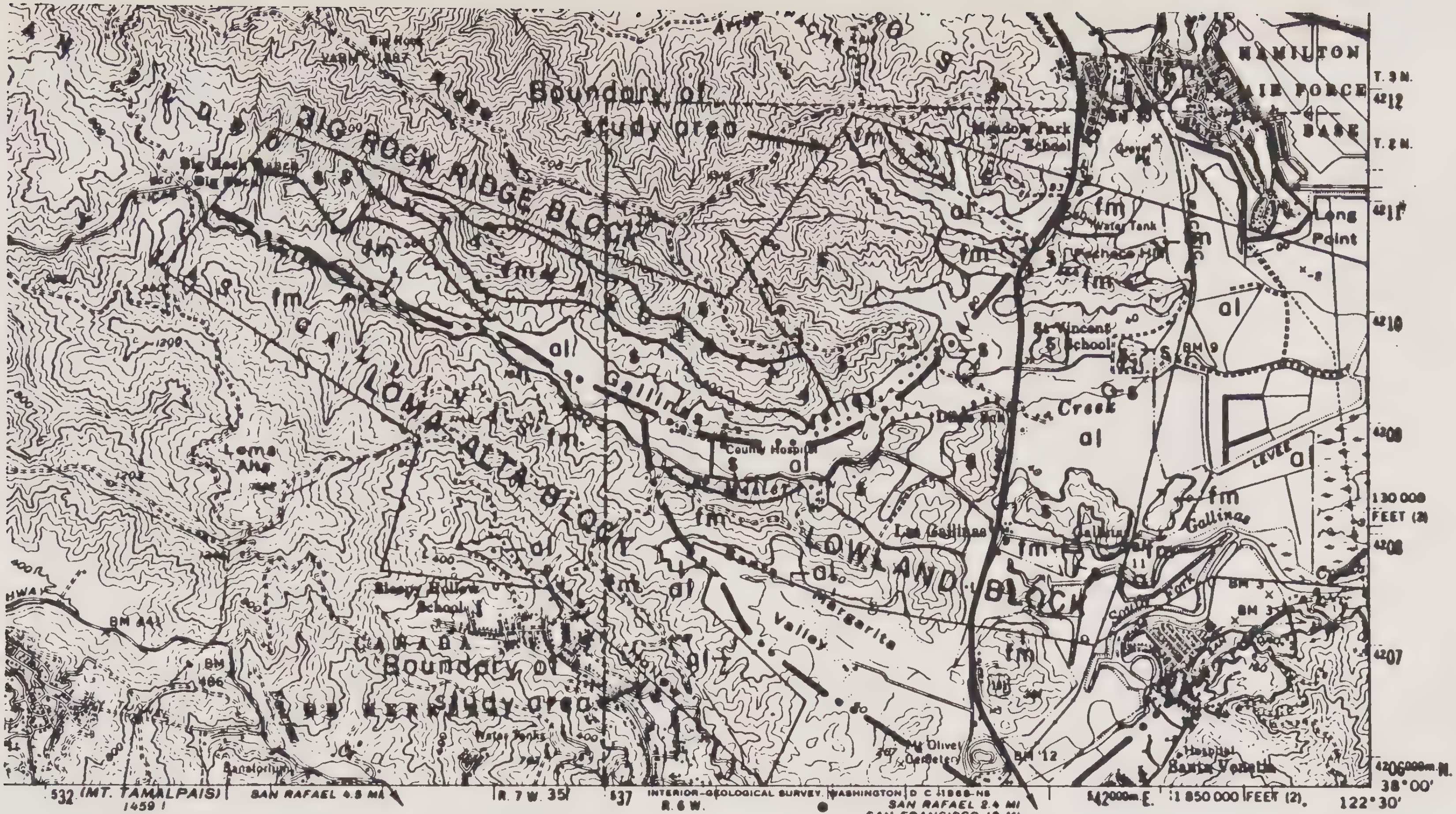
MINERAL RESOURCES

Sand and gravel deposits having potential as aggregate resources are present in the alluvium of Lucas Valley. The alluvium reportedly extends 30-40 feet in depth near the center of the valley in the vicinity of Luiz Ranch at the present outer limit of urbanization.

Minor amounts of manganese oxides were observed in several localities bordering Sleepy Hollow. The manganese minerals are associated with masses of thin-bedded chert. Chert has been quarried and used for road base material locally.

Impure clay deposits have been used as raw material for brick which were manufactured in the vicinity of the Gallinas rail stop, east of Highway 101. These deposits, probably the results of hydrothermal alteration of sandstone and shale, have now been worked out from a standpoint of commercial interest, and the brick yards have been closed.

Small outcrops of silica-carbonate rock (identified by the serpentine unit on the geologic map) were noted in hills north of San Dominco School. This type of rock is a common host for cinnabar, an ore mineral of mercury. Because the outcrops of silica-carbonate rock are small and no cinnabar was observed, these exposures are not regarded as being of potential commercial significance.



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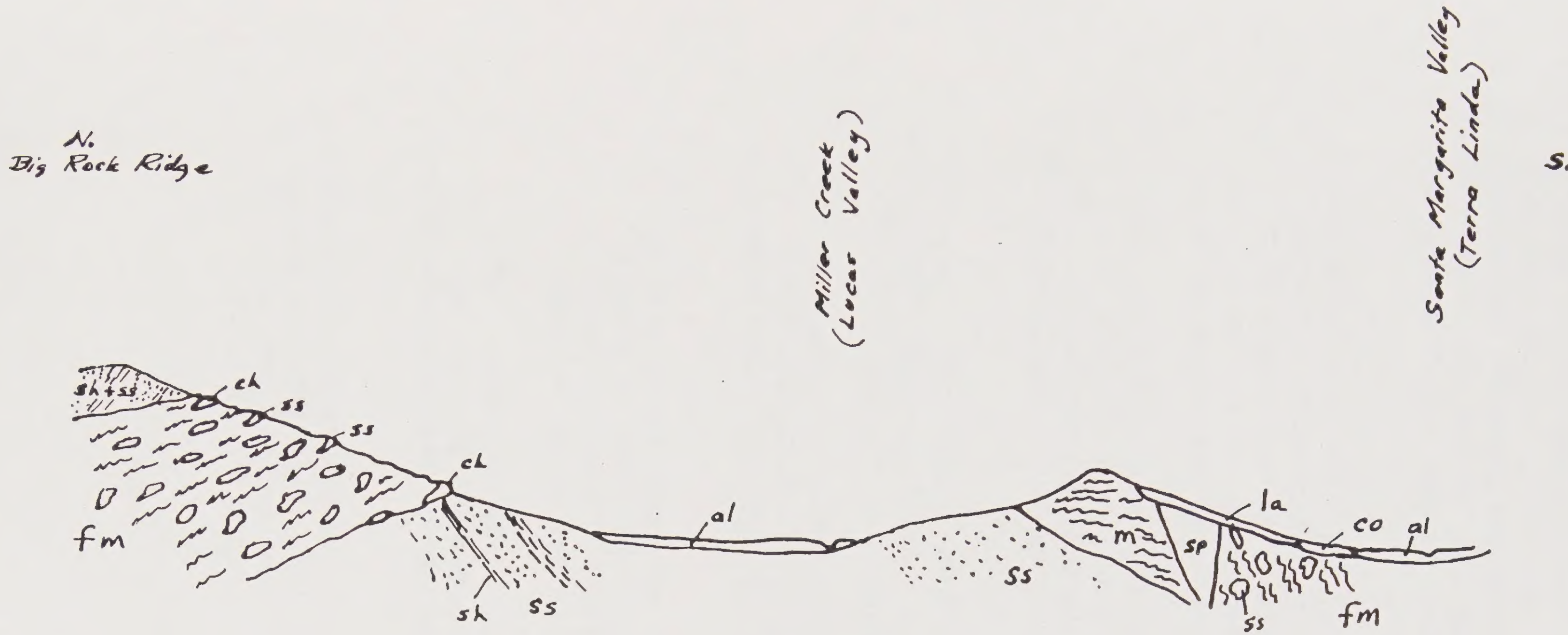
CONTOUR INTERVAL 80 FEET

GENERALIZED GEOLOGY AND INDEX MAP,
LUCAS VALLEY AREA, MARIN COUNTY, CALIFORNIA

fm	Franciscan melange, matrix and relatively small rock masses (knockers).
s	Large sandstone and shale slabs, relatively unsheared.
al	Alluvium of creek valleys and mud flats of San Francisco Bay.
——— ?— ········	Faults separating sandstone and shale slabs from other Franciscan melange, and selected local faults within the bedrock, questioned where uncertain. Suspected faults concealed under valley alluvium are indicated by heavy dotted lines.
━ •• ━	Boundaries of geomorphic blocks described in text.

FIGURE 5



Diagrammatic Cross Section Across Lucas Valley Near Center of Map

View Toward East

The crest of Big Rock Ridge is here composed of a slab of fine-grained sandstone and minor shale strata. East of this section, resistant massive sandstone provides an eastern buttress for this ridge. Beneath the crest is a zone of Franciscan melange which contains numerous equidimensional blocks (knockers) of chert, sandstone, and greenstone in a sheared rock matrix. The lower south-facing slope of Big Rock Ridge is underlain by another slab of shale and fine-grained sandstone which near the surface is dipping southward.

The ridge between Lucas Valley and Terra Linda is composed primarily of characteristic melange and a relatively persistent band of serpentine. The melange matrix is easily eroded and has failed by landsliding at numerous localities. The serpentine appears to be relatively stable although some slides originating higher up the slope have passed over the serpentine on their downward path.

Symbols and colors on this diagram are similar to those used on the geologic map.

FIGURE 6

SELECTED REFERENCES

Geologic and engineering aspects of San Francisco Bay fill: California Division of Mines and Geology Special Report 97, published in 1969. Contains important reports on engineering developments and on seismic problems and risks related to San Francisco Bay mud and to artificial fill on it. These were reports prepared for the San Francisco Bay Conservation and Development Commission.

Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks, and their significance to the geology of western California: California Division of Mines and Geology Bulletin 183. Describes in well-illustrated detail the various rock types within the Franciscan Formation, exclusive of the melange matrix.

Barosh, P. J., 1969, Use of seismic intensity data to predict the effects of earthquakes and underground nuclear explosions in various geologic settings: U. S. Geological Survey Bulletin 1279. Summarizes known aspects of seismic response of geologic materials in a well-illustrated manner.

Berkland, James O., 1963, Geology of the Novato Quadrangle: Unpublished Master's Thesis San Jose State College. Covers geology of the Lucas Valley area with an accompanying geologic map at scale 1:24,000.

Holway, R. S., 1914, Physiographically unfinished entrances to San Francisco Bay: University of California Publications in Geography, Vol. 1, No. 3. Discusses physiography of the Tennèssee (Elk) Valley area.

Hsu, K. J., 1968, Principles of melanges and their bearing on the Franciscan-Knoxville paradox: Geological Society of America Bulletin, Vol. 79, No. 8, pages 1063-1074. First published description of the general character of Franciscan Melange.

Lawson, A. C., 1914, San Francisco Folio, U. S. Geological Survey Geologic Atlas, Folio 193. The only published geologic map (Tamalpais Quadrangle) showing the geology of the Tennessee Valley area (scale 1:62,500).

Travis, R. B., 1952, Geology of the Sebastopol Quadrangle, California: California Division of Mines Bulletin 162. Discusses the geology of a large area including the Marin County coastal area north of Dillon Beach. Accompanied by geologic map scale 1:62,500.